

HyperSuprime: Project Overview

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ABSTRACT

HyperSuprime is a next generation wide field camera proposed for the 8.3 m Subaru Telescope. The targeted field of view is larger than 1.5 deg in diameter, which will give us roughly 10 times increase of the survey speed compared with the existing prime focus camera (Suprime-Cam). An overview of the current status of the feasibility study is given. More details are given in separate papers in this conference; Imaging optics: Komiyama et al.,¹ CCD: Kamata et al.,² Mechanical Design: Doi et al.³ and Electronics: Nakaya et al.⁴

Keywords: Wide Field CCD Camera

1. SUPRIME-CAM AND HYPERSUPRIME

Dark energy has become one of the central puzzles in natural science since its discovery in late 1990's. Because of its tenuous distribution, only astronomical observation could probe its existence. In order to understand the nature of dark energy, more precise observations are crucial. However, the required survey speed, which is defined by the product of the light gathering power measured by the surface area A of the primary mirror and the camera field of view Ω , is far beyond what can be provided by the existing astronomical facilities. This is the background of why next generation wide field projects have been planned and carried out, such as Dark Energy Survey (DES), Pan-STARRS, LSST.

Let us start from the introduction of one of the “existing” facilities: *Suprime-Cam* on the Subaru telescope.⁵ The Subaru prime focus has ϕ 30 arcmin un-vignetted field of view, which has been unique among 8~10 m class telescopes. Superb images better than 0.6 arcsec (FWHM) are routinely obtained thanks to the precision optics and mechanism built by Japanese firms (Figure 1). One example of Suprime-Cam images is shown in Figure 2(b) together with an image from the Hubble Space Telescope. The narrowband images that can be obtained with Suprime-cam are nearly comparable in depth to the Hubble Deep Field, but cover more than a hundred times the area.

It is interesting to note that the development project started in the early 1990's, well before the discovery of dark energy, and even before the discovery of Lyman break galaxies by Steidel et al.⁶ which opened the door to the high redshift universe based on the optical surveys, and triggered the boom of optical wide field surveys. In this sense, it was very farsighted of Profs. Kodaira (the first Project Scientist of Subaru) and Okamura (PI of Suprime-Cam) to make a decision to implement a prime focus on Subaru Telescope.

HyperSuprime is a proposed upgrade from Suprime-Cam. While keeping the same image quality as that of Suprime-Cam, we plan to expand the field size by more than 10 times. The image quality is a key issue; let us explain why by introducing a Weak Gravitational Lensing Survey as a probe of dark energy. Weak Lensing is a phenomenon in which the mass shears the shapes of background galaxies through gravitational effect. (As opposed to “weak lensing”, “strong lensing” gives rise to multiple images and strong warping of galaxy shapes).⁷ After we obtain images of galaxies, we characterize the shape of galaxies as is shown in Figure 3 where the shapes are represented as ellipses. The correlation of the shapes can be a measure of mass of intervening matter between

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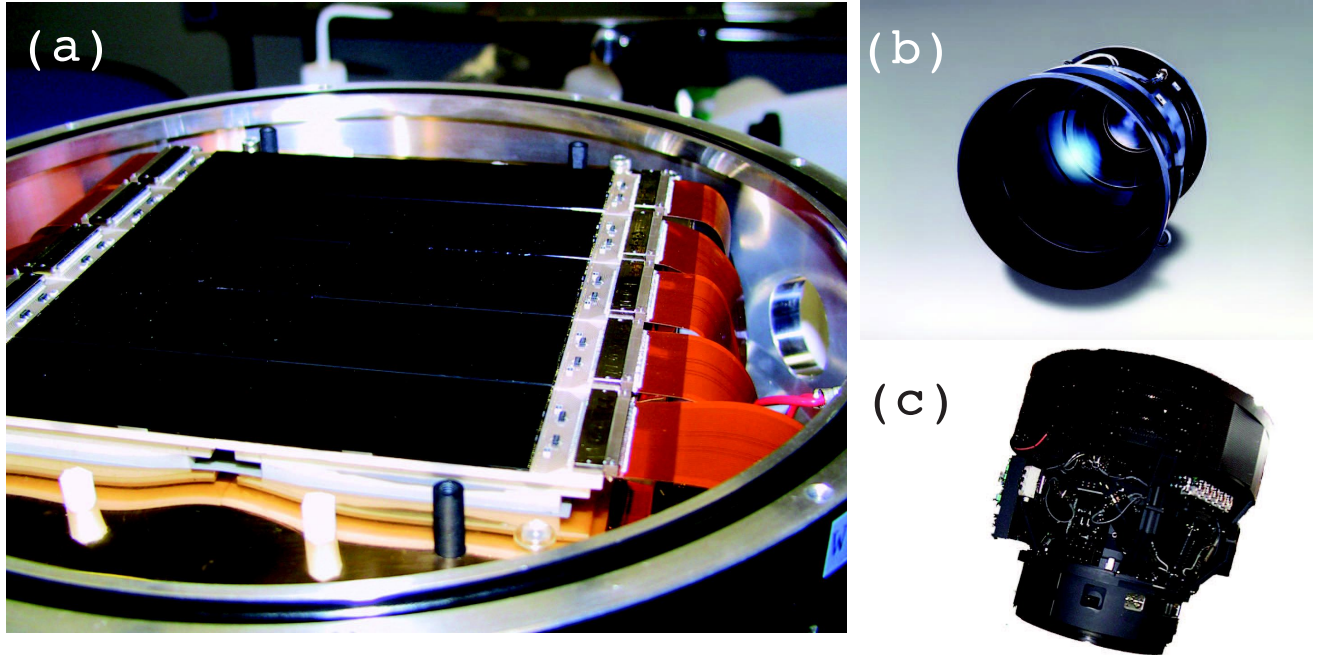


Figure 1. (a) Focal plane of Suprime-Cam which consists of ten MIT/LL CCID-20 CCDs mounted in the vacuum dewar. The physical size of the mosaic is 15 cm \times 12 cm and the longer side corresponds to 30 arcmin. (b) Subaru prime focus corrector lens designed and fabricated by Canon. The diameter of the first lens is roughly 50 cm. (c) Prime focus structure, designed and built by Mitsubishi Electric, which includes an instrument rotator, a hexapod with precise actuators for attitude control and a cable wrapper.

galaxies and the observer because the more massive the matter is, the greater correlation we have due to weak lensing. Dark Energy in turn can be estimated from the cosmic evolution of the mass distribution measured by weak lensing. Because dark energy is so tenuous, the imprint is very subtle. This is the very reason why we need a wide field of view to collect large samples of galaxies quickly. Note, however, that, if the images of galaxies are smeared for some reasons such as aberration of optics or unstable telescope tracking, we lose the information about dark energy. Even if we realized a wider field of view and the greater survey speed, the gain would be totally canceled out and little information about dark energy remains if the image quality becomes worse. Here again, the image quality is very important for HyperSuprime.

2. SYNERGY WITH WFMOS PROJECT

We have been discussing with Gemini the implementation of a planned WFMOS instrument (~ 4000 fiber spectrograph with 1.5 degree diameter field)⁸ on Subaru Telescope. If HyperSuprime and WFMOS could share the wide field corrector lens, we could reduce the cost of instruments. WFMOS is designed to carry out the baryon oscillation survey which is one of the complementary dark energy probes to weak lensing. Therefore, we could expect synergy effects scientifically as well. The Sloan Digital Sky Survey (SDSS) realized using a 2.5 m telescope has proved that systematic imaging and spectroscopic wide field surveys provide us with plenty of scientific achievements. Because HyperSuprime/WFMOS is supposed to be a natural extension of SDSS implemented on an 8 m telescope, the unprecedented survey speed will lead us to new discoveries.

3. FEASIBILITY STUDY OF HYPERSUPRIME

The design goal of HyperSuprime is summarized in Table 1. The field of view that we originally pursued was 2.0 deg in diameter.⁹ This requires significant reconstruction of the top ring central hub of the telescope, which could

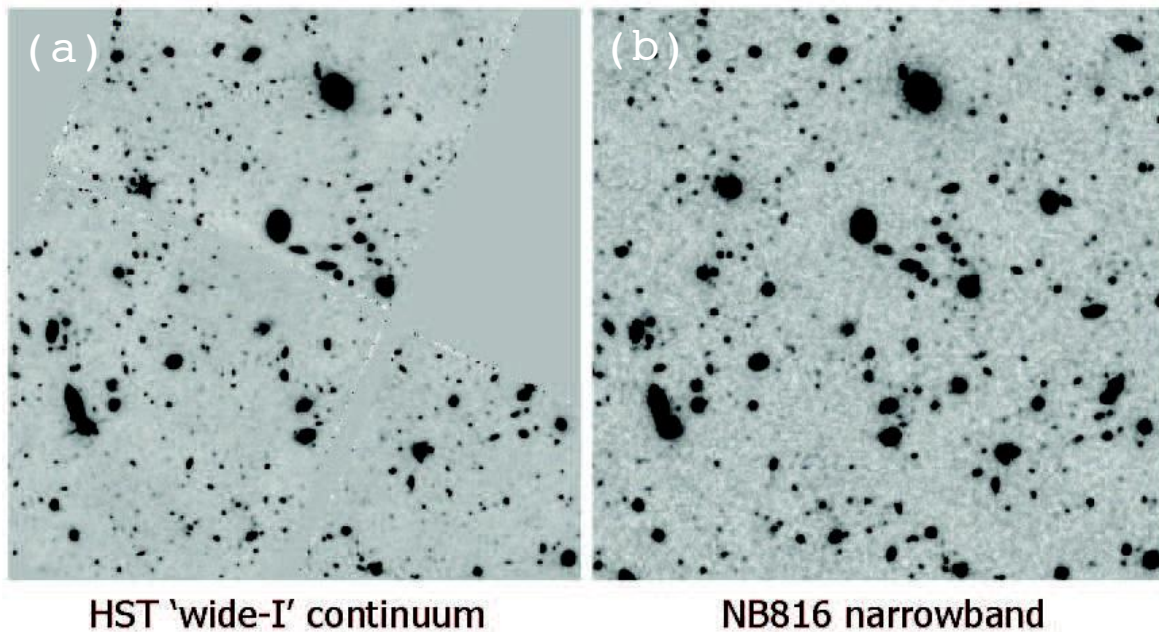


Figure 2. (a) The Hubble Deep Field imaged with the WFPC2 on HST through the F814W continuum filter. (b) The same region imaged from the ground through a narrow band NB816 filter using Suprime-Cam. (Courtesy of E. Hu).

result in increase of the cost and shutdown time of the telescope. We therefore started exploring another option which makes the impact on the existing central hub minimum, and provides a 1.5 degree field. Maximum weight allowed for the instruments should not exceed the current instrument weight significantly. The decision about the field size and the telescope interfacing will be made after detailed discussions with the telescope builder, Mitsubishi Electric, which are scheduled to commence in October 2006.

The optical specification is represented as the 80 % encircled energy diameter, D_{80} . In the red band ($\lambda > 600$ nm), where shape measurement of galaxies are usually carried out for weak lensing analysis D_{80} should be equivalent with what we obtain on Suprime-Cam. If necessary, we compromise the image quality in blue wavelength up to $D_{80} = 0.4$ arcsec. This would be acceptable since good seeing is usually expected and desired scientifically in longer wavelength.

Because the typical exposure time of Suprime-Cam is about 4 ~ 5 minutes (the limit is due to the sky brightness especially in red-band), the current readout time of 50 sec does not pose significant impacts on the observing efficiency although reduction to about 20 sec would be ideal. Since the observation style will not change significantly on HyperSuprime, a 20 second readout speed would be satisfactory.

3.1. Mechanical Structure

The prime focus unit which holds Suprime-Cam and the existing corrector (Figure 1(c)) should be entirely re-designed to have HyperSuprime and the new wide corrector on the telescope. Figure 4(a) shows the conceptual design of ϕ 1.5 deg option mechanics. The structure consists of two units: Camera Unit and Lens Unit. The lens unit is attached to the telescope from zenith, and the lens barrel is supported by the hexapod actuators so that the attitude can be controlled. The camera unit is attached to the end of the lens barrel by a set of clamps. The Camera Unit is interchangeable with the WFMOS fiber positioner. In this option, the existing central hub is supposed to be used with minimum modifications.

On the other hand, ϕ 2 deg option requires replacement of the inner hub (and the telescope spiders) so that it can accommodate the larger lens barrel and hexapod actuators (Figure 4(b)). Because we must maintain the



Figure 3. Part of a Suprime-Cam image with measured galaxy shapes superimposed. The mass of intervening matter between the galaxies and the observer can be estimated from the correlation of pairs of the galaxy shapes (while lines in the figure) using weak lensing technique. The more massive the matter in the universe is, the higher statistical correlation we will observe.

Table 1. Design Goal of HyperSuprime

Field of View	ϕ 2.0 deg max (ϕ 1.5 deg considered)
80 % encircled energy diameter	< 0.3 arcsec ($600 \text{ nm} < \lambda < 1100 \text{ nm}$) < 0.4 arcsec ($400 \text{ nm} < \lambda < 600 \text{ nm}$)
Maximum weight (including lens)	3~3.5 t
Filters stored	4 minimum
Readout time of arrays	$< \sim 20$ sec

same mechanical interface for the existing secondary mirrors, we propose a “dual hub structure” shown here. The inner hub is designed to mimic the existing hub to which the secondary mirrors are attached from the bottom. The lens unit of ϕ 2 deg option is attached from the bottom as well, and the camera unit is attached from the zenith to the lens unit. The inner hub is supported by hexapod actuators, and joined with the outer hub so that the attitude of the inner hub and HyperSuprime can be controlled. To minimize the weight increase, we plan to adopt CFRP material for most of the mechanical components including the lens barrel, hub, and the spiders. Because of its complexity, the cost increase is inevitable in this option.

The specification in Table 1 is opto-mechanical integrated performance. Mechanical flexure should be smaller than optical tolerance, and the accuracy of the instrument rotator mechanism and actuator should be designed so that they will not affect the integrated performance. Although we have not finished all of the detail design yet, the FEM analysis shows promising results. Refer to Doi et al.³ (2006 this proceedings) for more detail about mechanical structure and components of HyperSuprime.

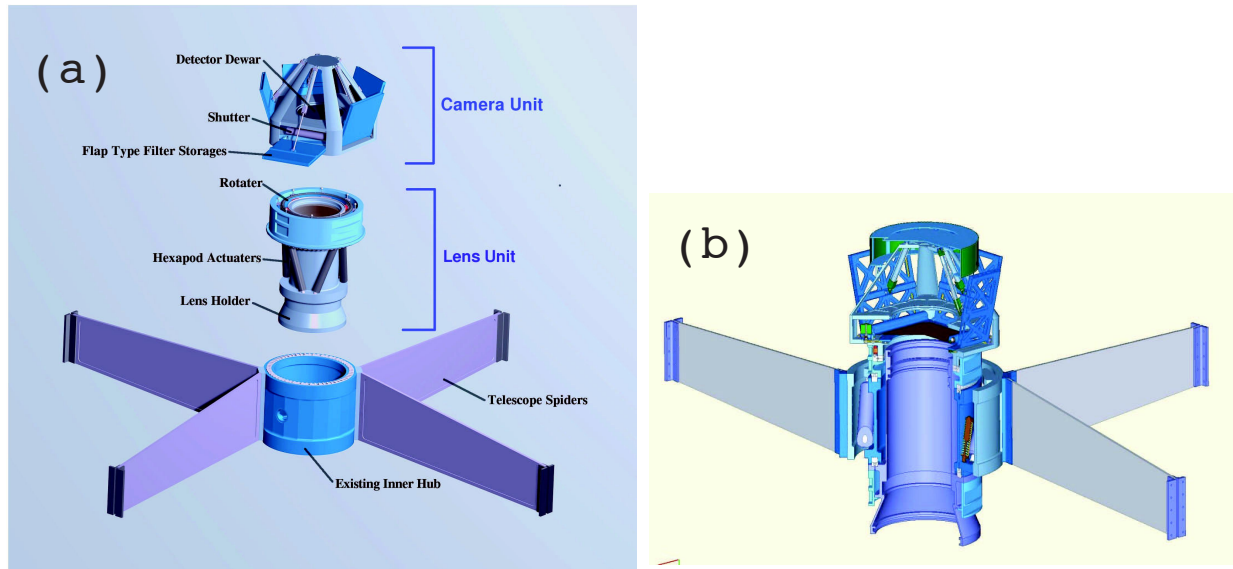


Figure 4. HyperSuprime structure (a) ϕ 1.5 deg option, (b) ϕ 2.0 deg option.

Two issues still remain unresolved about the mechanism as of writing; (1) how to fix the lens unit with the central hub, (2) the development of compact high accuracy actuators for the hexapod. Since the former is a part of telescope interfacing, this will be discussed with Mitsubishi later this year. We will make a prototype of the actuator to see if the targeted performance can be actually obtained.

3.2. Optics

Komiyama et al. (2004)⁹ discussed a possible optical design for ϕ 2 deg option and they further improved the design recently¹ to have more feasible manufacturability by reducing the asphericity. They also discuss the ϕ 1.5 deg design, and these satisfy our design goal, and are plausible.

There is an independent line of optical design study that originally came from the WFMOS feasibility study. Peter Gillingham, who used to work on the feasibility study at Anglo-Australian Observatory, and now joins the HyperSuprime team, has improved the original design significantly to satisfy both HyperSuprime and WFMOS optical requirements. HyperSuprime requires smaller images but does not require as wide wavelength coverage as WFMOS; WFMOS allows larger field curvature than HyperSuprime does and so on. Figure 5 shows the configuration of the latest optical design. The first lens is ϕ 900 mm, and surfaces designated “*” are aspheric. The atmospheric dispersion corrector is implemented as twin doublets without sacrificing image qualities. Note that in imaging mode, the D_{80} is as good as 0.3 arcsec even in the blue band below 600 nm.

Armed with these optical designs, we are about to start contacting optical firms to investigate the feasibility of manufacturing. Preliminary responses show no significant difficulties in building the ϕ 1.5 deg option optics. Some R&D efforts will be necessary to see if ϕ 2.0 deg option is feasible.

3.3. CCD

We need 176 CCDs to fill the 2 degree field of view, and still more than a hundred even for 1.5 degree option. Thanks to enormous efforts of commercial vendors such as SITe and E2V, the supply of the large format CCD for astronomy has become significantly improved and stable compared with the late 90's when we were building Suprime-Cam. However, considering the price tag of \$50k ~ \$100 k for a typical 2048×4096 (13.5 ~ 15 μ m) CCD, the production yield must not be so high. So the procurement of so many CCDs remains a risk factor for the project. This is part of our motivation to start a collaboration with Hamamatsu to develop fully depleted CCDs (FDCCDs), which do not require a delicate chemical etching process to build back-side illuminated devices,

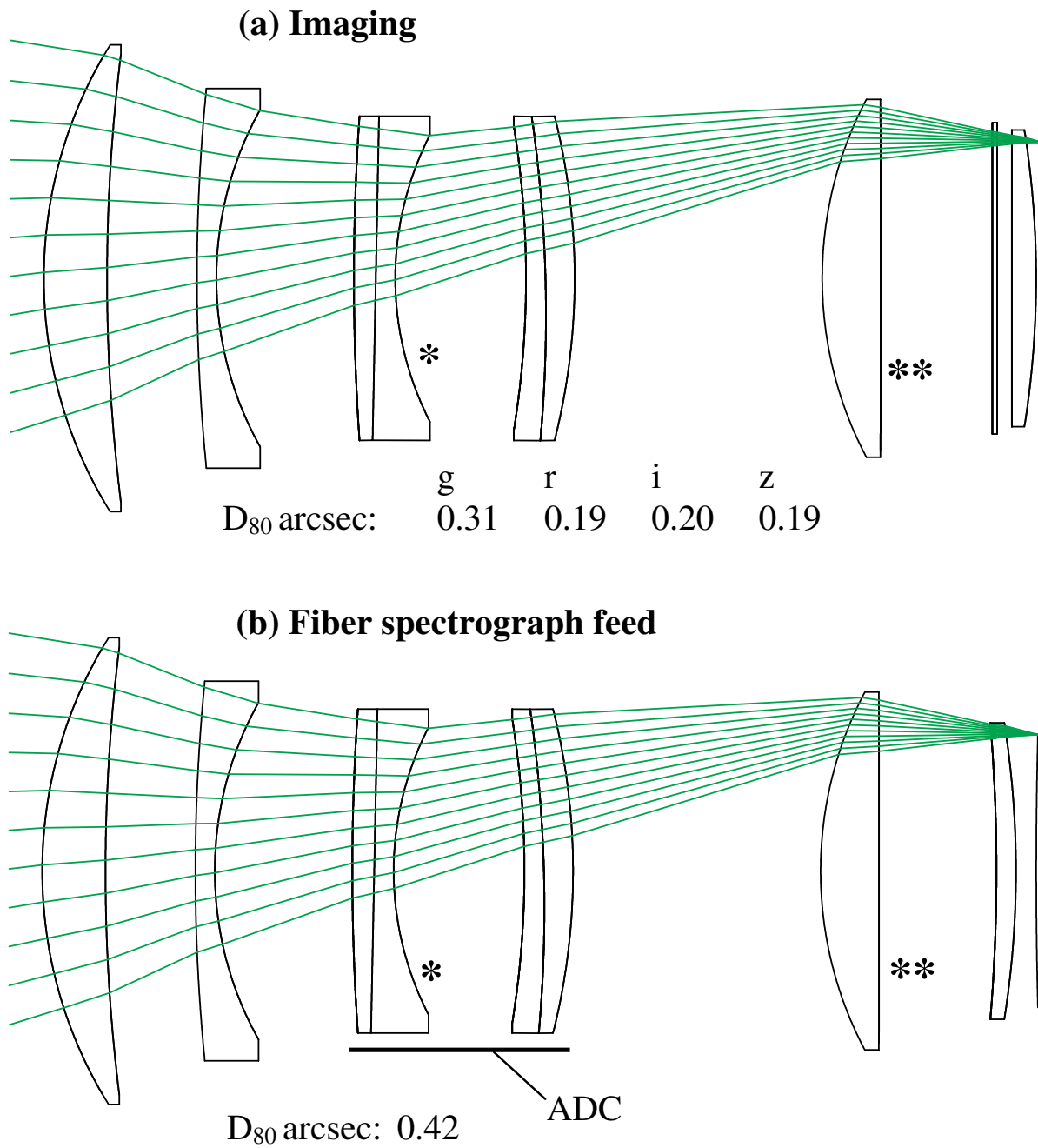


Figure 5. Optical design of ϕ 1.5 deg option. The last element is exchanged between the two modes: (a) imaging for HyperSuprime (b) spectroscopy for WFMOS. D_{80} calculated for the zenith distance of 65 degree is shown.

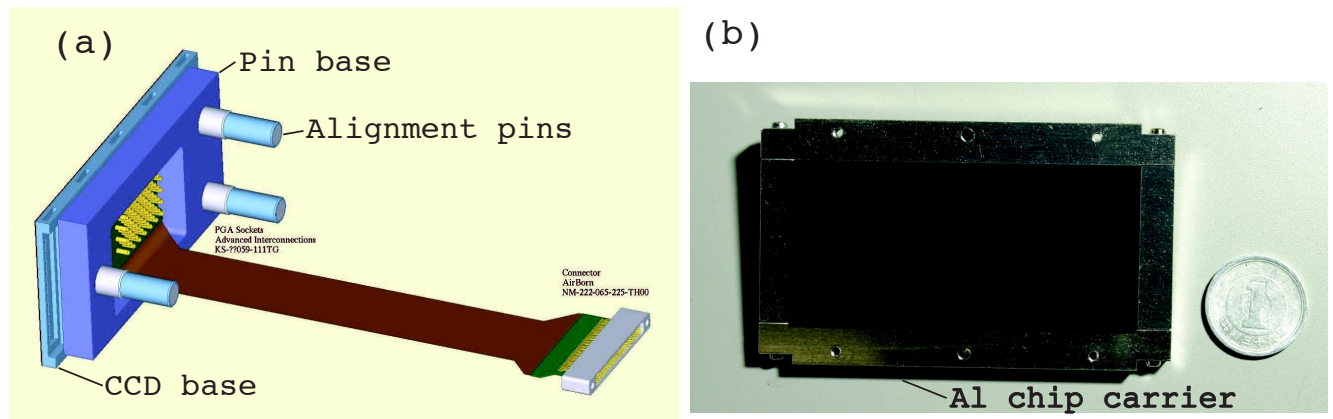


Figure 6. (a) Package design of Hamamatsu fully depleted 2048×4096 ($15 \mu\text{m}$ pixel) CCD. CCD die is epoxied to a ceramic CCD base that has interconnections of pads and pins inside. The CCD base is then epoxied on to a Pin base which has alignment pins. This “pin-base” scheme is equivalent with what was adopted for Suprime-Cam.⁵ The flex cables are designed to connect the CCD and the electronics. (b) actually delivered 2k4k CCD with an aluminum carrier surround to protect edges.

and one could hope that the yield would improve further. The more important advantage of FDCCD is higher quantum efficiency in the red band thanks to the thicker depletion layer.

After several years of the collaborative works with Hamamatsu, we recently obtained the first $2k \times 4k$ ($15 \mu\text{m}$ pixel) four side buttable CCD (Figure 6). The evaluation test shows that basic specifications such as CTE, QE, dark current and read noise are all met. The charge diffusion was measured using a 450 nm pin hole image, and it is less than half of the pixel size, which is small enough. According to the X-ray QE measurement, the depletion layers reach up to $200 \mu\text{m}$ as designed. Please refer to Kamata et al.(2006)² to know more about characterization of the Hamamatsu FDCCD.

3.4. Electronics

Subaru has its own CCD readout electronics system developed in house:¹⁰ MFront for analog processing and MESSIA for digital processing. When we readout the entire array of HyperSuprime in 10 seconds the data rate reached up to 275 MByte/sec. It can be handled by 4 independent sets of current version of MESSIA5, and the data are transferred to a remote host computer via Gbps Ethernet. The host manages the data and stores them to the disk during the next exposure sequence, which is easy because the typical exposure time of HyperSuprime will be longer than 4 minutes.

The analog part will be more challenging considering the large number of output channels (4 outputs/CCD). Wiring and the feed-through of the vacuum chamber become overwhelming if one adopts conventional lead wire connections. We plan to develop low power compact electronics based on the MFront, and locate most of the electronics up to the ADC inside the dewar. Refer to Nakaya et al.(2006)⁴ for more about the HyperSuprime electronics.

4. COMPARISON WITH OTHER PROJECTS

Several wide field imaging projects are in progress including DES, Pan-STARRS and LSST. All of the projects have already been funded at least in part, and the expected first light are around 2009 ~ 2011. (“Pan-STARRS-1”, which is the first telescope of the project, is scheduled to have the first light in 2006). HyperSuprime should be completed sometime before 2010 to be fully competitive in probing dark energy.

Table 2 compares the scale of these projects in terms of the targeted survey speed and the cost. HyperSuprime would be ranked somewhere between Pan-STARRS and LSST. However, this is not the whole story. As we stressed in Section 1, the true key to succeed in the dark energy survey is the image quality. Among them, Subaru

is the only telescope that has already demonstrated that image qualities of better than 0.6 arcsec (FWHM) can be routinely obtained. This is one of the strongest advantages of the HyperSuprime project.

Table 2. Comparison of the scale of wide field imaging projects. $A\Omega$ is survey speed. The value of HyperSuprime in brackets comes from the ϕ 1.5 deg option. The costs shown here are taken from various literatures, and might not be accurate, but would reflect the scale of the projects. Cost estimation for HyperSuprime has not yet been finished. New Tel. means the project builds a new exclusive use telescope.

Project	$A\Omega$	Cost [M\$]	Note
DES	37	~ 30	CTIO 4m
Pan-STARRS	13.4 \times 4	~ 50	New Tel. 1.8 m \times 4
HyperSuprime	162 (91)	T.B.D.	Subaru 8.3 m
LSST	329	~ 300	New Tel. 6.5 m equiv.

5. SCHEDULE

From October 2006, we will start discussion with Mitsubishi Electric about the telescope interfacing. We expect that the field size option can be selected in May 2007. If the submitted Grant-In-Aid by the Japanese government is approved this year, we will be able to do a one year final design study from June 2007 to June 2008. Then, roughly two years production phase follows, and we would expect the first light sometime in summer 2010.

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